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LAUNCH ENVIRONMENT PROFILES FOR SOUNDING ROCKETS AND SPACECRAFT

by W. J. Neff and R. A. Montes de Oca

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SUMMARY

The Launch Phase Simulator, which is being developed by the Goddard Space Flight Center, must provide several different functions—individually or in combination—for simulating the environmental conditions encountered by the payload of sounding rockets and unmanned spacecraft from liftoff to last stage burnout. A survey has been made of the sounding rockets and spacecraft launch vehicles that NASA is utilizing or will use in the near future, and representative profiles are plotted to show their time history and interrelation of parameters. The following parameters are included in the profiles: acceleration, (longitudinal and lateral), pressure, vibration, acoustics, heating, and spin. From these profiles, an overall envelope of launch environmental parameters has been constructed.

CONTENTS

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FOR
SOUNDING ROCKETS AND SPACECRAFT*

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INTRODUCTION

An environmental test facility called the Launch Phase Simulator is being developed by Goddard Space Flight Center (GSFC). The purpose of this facility is to provide simulation of the environmental conditions encountered by the payloads of sounding rockets and unmanned spacecraft during the launch phase of flight. The most important feature of the launch environment is that mechanical input (vibration, shock, acoustics, spin) and thermal-vacuum inputs are imposed on a payload in a varying acceleration field. The fundamental design criterion of the Launch Phase Simulator is this combination of environmental inputs.

To provide simulation of the environmental parameters acting during the launch phase, the magnitudes of these parameters and the extent to which they are combined must be known. Therefore, a survey has been made of the sounding rockets and unmanned spacecraft launch vehicles that NASA is using or will use in the near future. The results of this survey are presented herein as launch environment profiles for representative missions. The parameters given in these profiles include acceleration, pressure, vibration, acoustics, heating, and spin. From these profiles, an overall envelope of the launch environment parameters can be constructed.

The launch profiles have been prepared to assist in developing the Launch Phase Simulator facility. The material has been organized to fulfill the need for an overall envelope of launch environment parameters. However, this material is not considered suitable for specific applications, such as programming individual spacecraft environmental tests.

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LAUNCH ENVIRONMENT PROFILES FOR SOUNDING ROCKETS

Launch environment profiles for the following sounding rockets have been included in the study:

Name	Designation
Nike-Asp	ASPAN 150
Aerobee 150 A	---
Javelin	Argo D-4
Aerobee 300 A	Spaerobee
Iris	52 KS 3850, Marc 13A1
Nike-Cajun	---
Journeyman	Argo D-8
Journeyman B	TS609 (Blue Scout, Jr.)

The data gathered for this work are incomplete with regard to some parameters, and a summary of availability is presented in Table 1. The following paragraphs contain general comments for each of the parameters.

Table 1

Availability of Data on Launch Profile Parameters for Sounding Rockets.*

Sounding Rocket	Acceleration, Longitudinal	Acceleration, Lateral	Altitude (Pressure)	Vibration	Acoustics	Heating	Roll Rate (Spin)	Dynamic Pressure	Mach Number
Nike-Asp	x		x			x	x		
Aerobee 150 A	x		x			x	x		
Javelin	x		x	x	x	x	x	x	x
Aerobee 300 A	x		x			x	x		
Iris	x		x	x		x	x		
Nike-Cajun	x		x			x	x		
Journeyman	x		x			x	x	x	x
Journeyman B	x		x	x		x	x		

*Availability of data is denoted by the letter "x."

1. Acceleration

   (a) Longitudinal: Complete data are available, either calibrated or tested. Test results are in good agreement with the calibrated data. Table 2, which shows the maximum acceleration achieved for different stages of various rockets with nominal payloads, illustrates the wide range of maximum accelerations and time of occurrence.

<div align="center">

Table 2

Maximum Stage Acceleration Versus Time for Sounding Rockets.*

</div>

Sounding Rocket	1st Stage		2nd Stage		3rd Stage		4th Stage	
	Accel. (g)	Time (sec)	Accel. (g)	Time (sec)	Accel. (g)	Time (sec)	Accel. (g)	Time (sec)
Nike–Asp	39.6	2.8	49.3	23.1	---	---	---	---
Aerobee 150 A	11	2.5	9.1	55	---	---	---	---
Javelin	17.5	4	16.3	13	34.8	28	12.6	87
Aerobee 300 A	10.9	2	8.5	51	57.5	54	---	---
Iris	13.9	1	9.6	52	---	---	---	---
Nike–Cajun	41.7	2.8	64.1	24	---	---	---	---
Journeyman	9.6	2.5	14.8	43	33.8	51	12.7	97
Journeyman B	7.6	2.6	7.1	72	27.3	105	12.9	146

*The maximum acceleration for each rocket is underlined.

(b) Lateral: No record of lateral acceleration for these rockets was found during the survey.

2. Altitude (pressure)

Altitude versus time and the corresponding atmospheric pressure profile are depicted for each rocket. These profiles vary with payload.

3. Vibration

Vibration profiles are not plotted because of the lack of appropriate data. However, vibration inputs may be expected during the whole launch phase and will be particularly severe during the burning time of certain stage motors. The list of data sources (Bibliography, page 32) includes several references for vibration data.

4. Acoustics

Data on acoustic excitation have been presented for the Javelin (Argo D-4) only.

5. Heating

(a) External: The external temperatures plotted for each sounding rocket have been presented for an assumed low launch angle (approximately 70 degrees) and a nominal payload. At higher launch angles the temperature will be lower.

(b) Internal: Heating of the payload compartment after launch is a function of the compartment temperature prior to launch, vehicle flight path, duration of flight, heat output of the payload,

and compartment configuration. Since the powered flight time for sounding rockets is very short (in general, less than 100 sec), the payload compartment temperature rise will be small.

6. Roll rate (spin)

Roll rates are presented as a function of time. There is a wide range, from 0 spin to 12 rps, occurring at different values of acceleration and pressure.

7. *Dynamic pressure and Mach number*

Dynamic pressure and Mach number are also plotted for those rockets on which data are available.

Figures 1 through 8 give the launch profiles for the sounding rockets. Descriptive data for each rocket accompany the figures. Profiles are given for nominal payload unless otherwise specified.

Nike-Asp

Designation: ASPAN 150
Launch vehicle
  1st: Nike M5 Booster
  2nd: Asp-I
Payload size: See sketch

Payload weight (lb)
  Minimum: 25
  Nominal: 50
  Maximum: 100

6.0   1.280

34.2   2.31

28.2

26.6

6.5
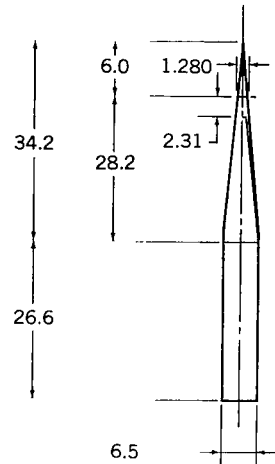
(Dimensions in inches)
(Nominal available payload volume = 0.64 cu ft)

Figure 1—Launch profile for Nike-Asp sounding rocket.

Aerobee 150 A

Launch vehicle
    1st: 2.5 KS 18000
    2nd: Aerobee 150 A
Payload size: See sketch

Payload weight (lb)
    Minimum: 100
    Nominal: 200
    Maximum: 300

31 caliber OGIVAL SECTION

87.8

9.4

BATTERY EXTENSION

NOSE EXTENSION

15.00
Diam.

15.00

(Dimensions in inches)
(Nominal available payload volume, including extensions = 6.90 cu ft)
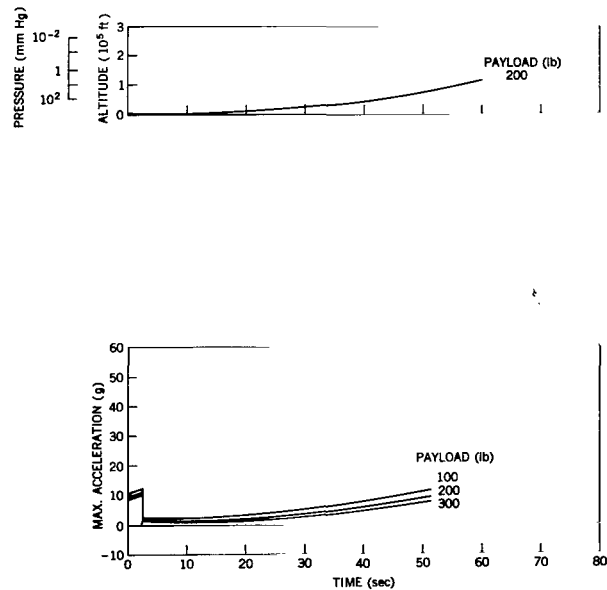
Figure 2—Launch profile for Aerobee 150 A sounding rocket.

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Javelin (Argo D-4)

Designation: Argo D-4
Launch vehicle
  1st: Honest John M6 Booster
  2nd: Nike M5 Booster
  3rd: Nike M5 Booster
  4th: Altair (X248-A6)
Payload size: See sketch

Payload weight (lb)
  Minimum: 20
  Nominal: 125
  Maximum: 175

(Dimensions in inches)
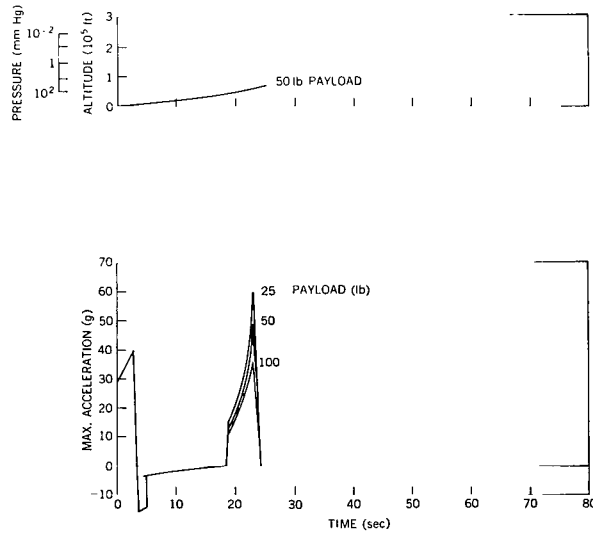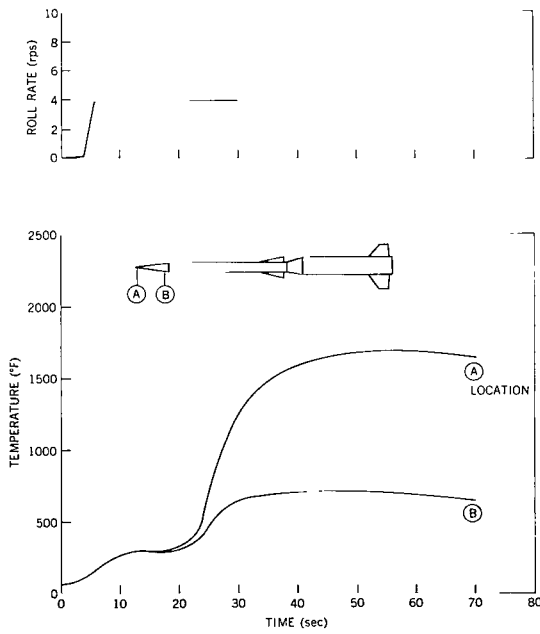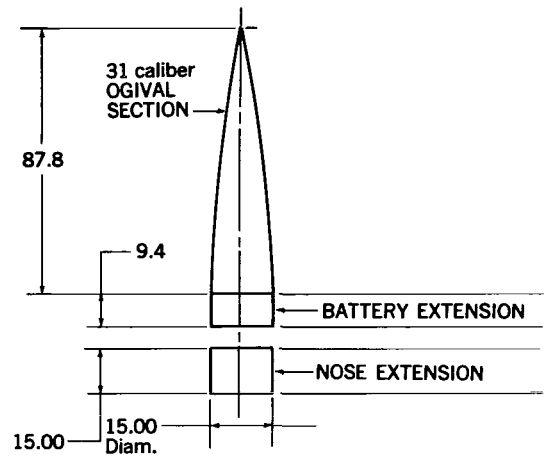(Nominal available payload volume = 1.4 cu ft)
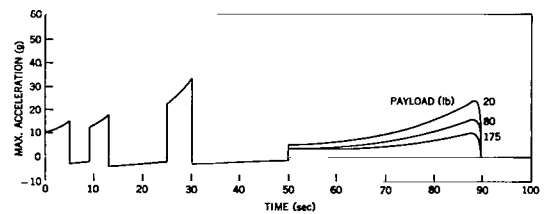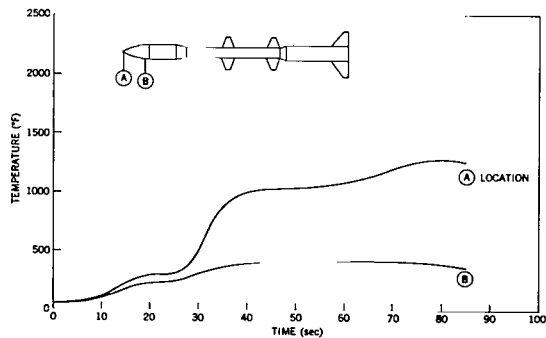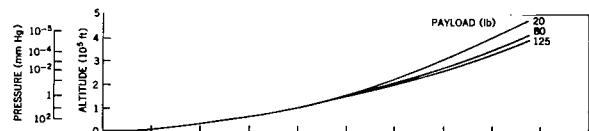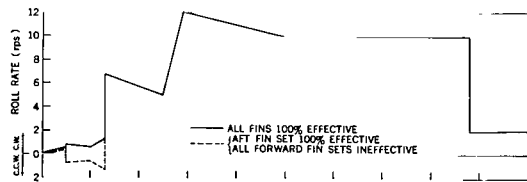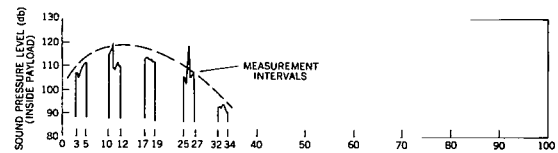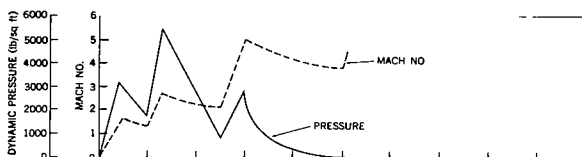
Figure 3—Launch profile for Javelin sounding rocket (Argo D-4).

Aerobee 300 A

Designation: Spaerobee
Launch vehicle
  1st: Aerojet (2.5 KS 18000)
  2nd: Aerobee 150 A
  3rd: Sparrow III (1.8 KS 7800)
Payload size: See sketch

Payload weight (lb)
  Minimum: 20
  Nominal: 60
  Maximum: 100

22.7

29.5

8.00 Diam.
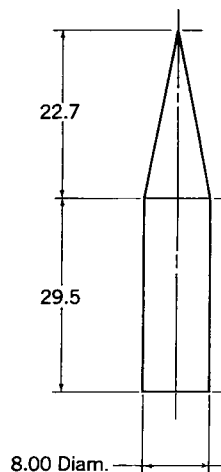
(Dimensions in inches)
(Nominal available payload volume = 0.9 cu ft)
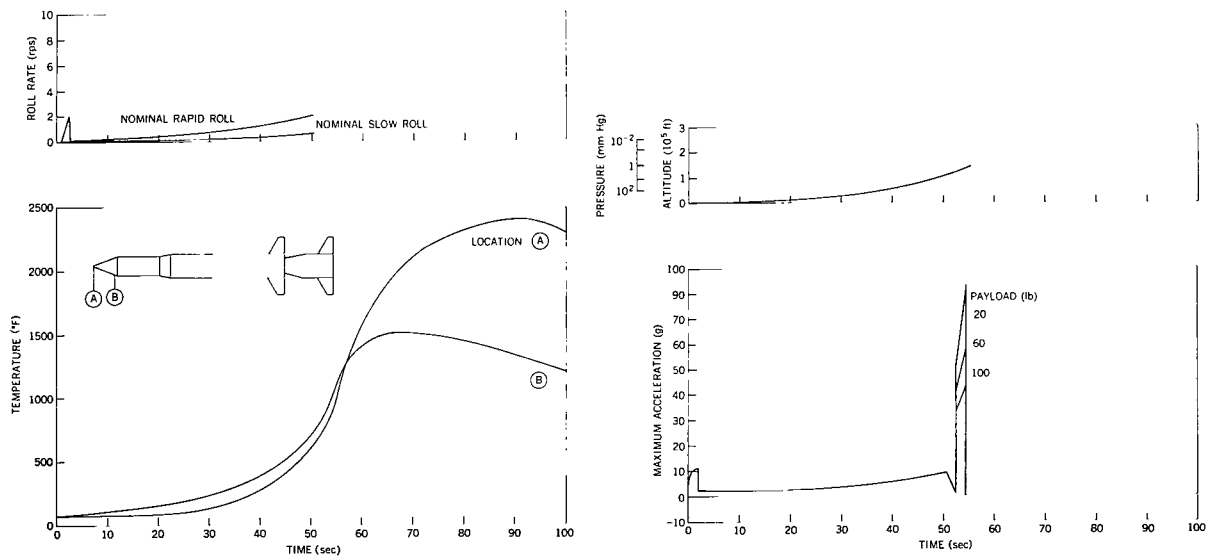
Figure 4—Launch profile for Aerobee 300 A sounding rocket.

Iris

Designation: 52 KS 3850, Marc 13A1
Launch vehicle
    1st: 0.8 KS 18800, Marc 14B1
    2nd: 52 KS 3850
Payload size: See sketch

Payload weight (lb)
    Minimum: 75
    Nominal: 100
    Maximum: 200
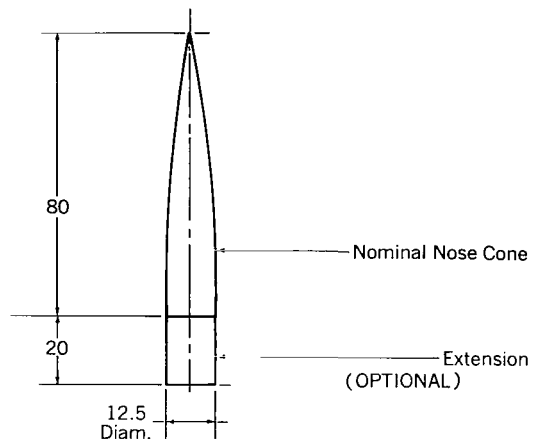
(Dimensions in inches)
(Nominal available payload volume = 4.5 cu ft;
with 20-in. cylindrical extension = 5.8 cu ft)
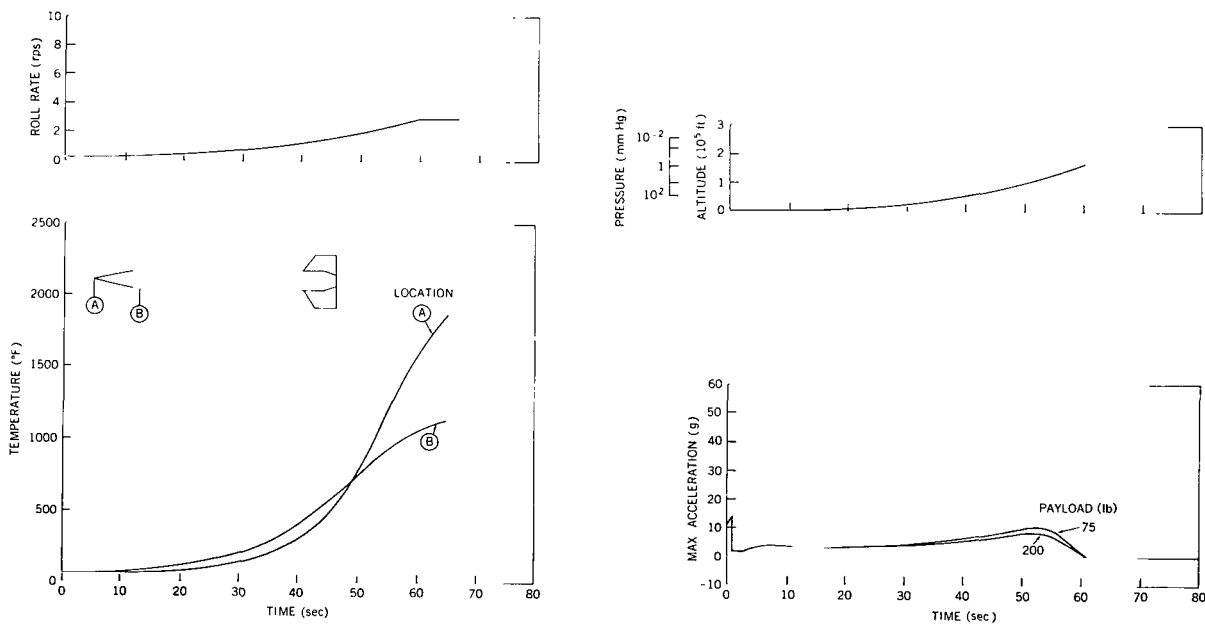
Figure 5—Launch profile for Iris sounding rocket.

Nike-Cajun

Launch vehicle
  1st: Nike M5 Booster
  2nd: 2.8 KS 8000 Cajun
Payload size: See sketch

Payload weight (lb)
  Minimum: 25
  Nominal: 50
  Maximum: 100
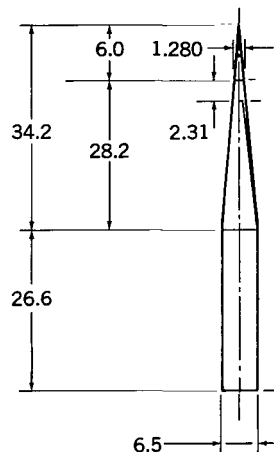
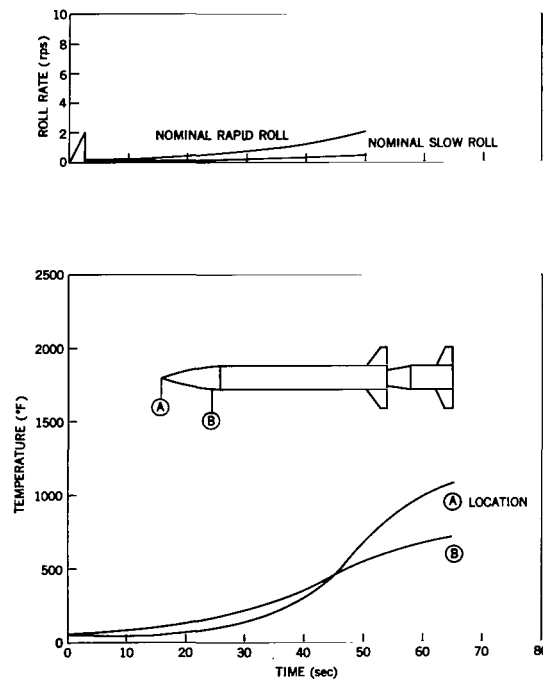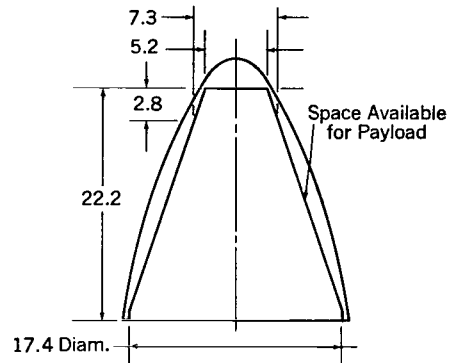(Dimensions in inches)
(Nominal available payload volume = 0.64 cu ft)
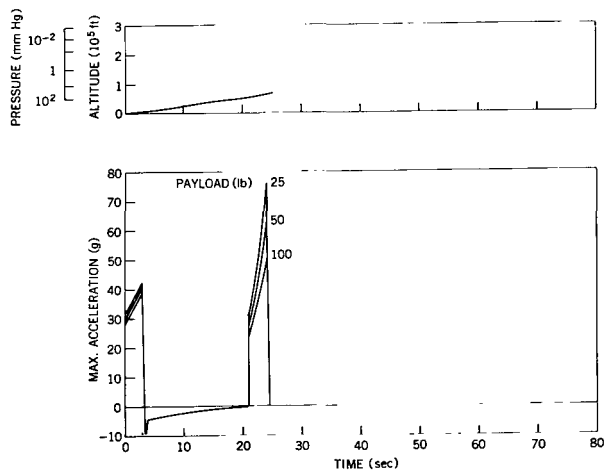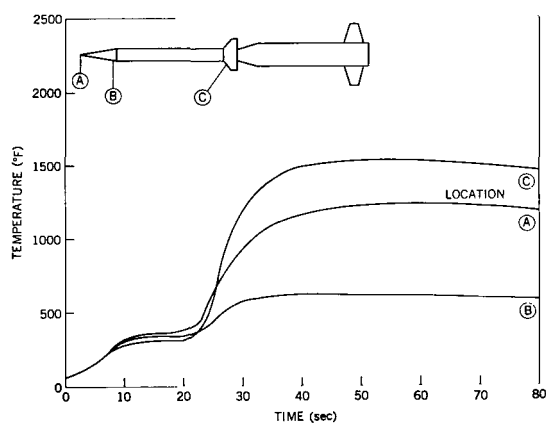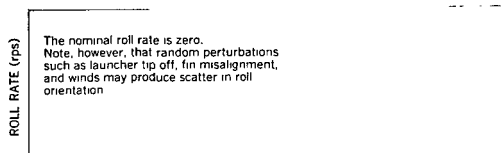
Figure 6—Launch profile for Nike-Cajun sounding rocket.

Journeyman (Argo D-8)

Designation: Argo D-8
Launch vehicle
  1st: Pollux XM-33E6 plus two auxiliary
      Recruit (XM-19E1)
  2nd: Lance XM-25
  3rd: Lance XM-25
  4th: Altair X248-A6
Payload size: See sketch

Payload weight (lb)
  Minimum: 75
  Nominal: 125
  Maximum: 175
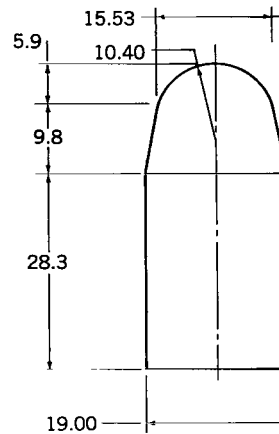
(Dimensions in inches)
(Nominal available payload volume = 7 cu ft, estimated)
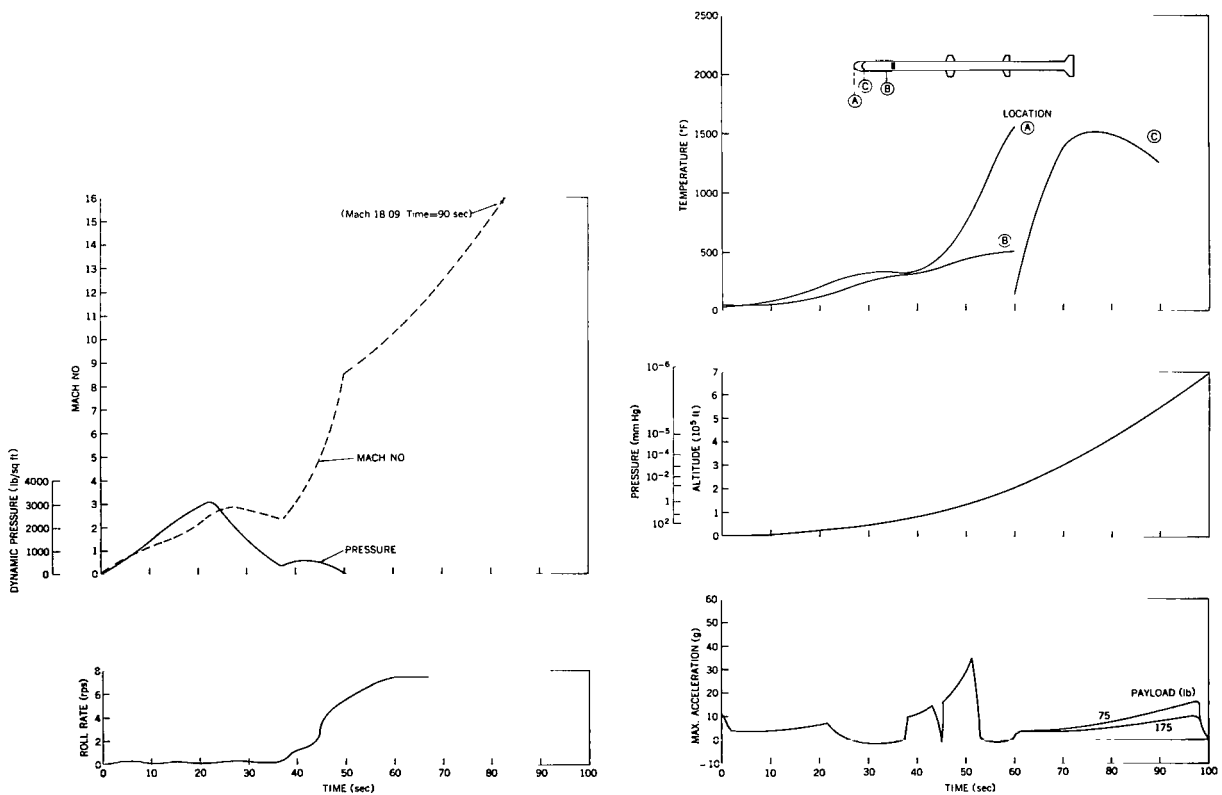
Figure 7—Launch profile for Journeyman sounding rocket (Argo D-8).

Journeyman B

Designation: TS 609A (Blue Scout, Jr.)
Launch vehicle
   1st: Castor (XM33-E8)
   2nd: Antares (X254-A1)
   3rd: Alcor (AJ10-41)
   4th: Cetus (NOTS 100A)
Payload size: See sketch

Payload weight (lb)
   Nominal: 30
   Intermediate: 50
   Maximum: 100

20°

38.9

17.0 Diam.
Spherical Motor
(NOTS Inyokern)

21.0 Diam.
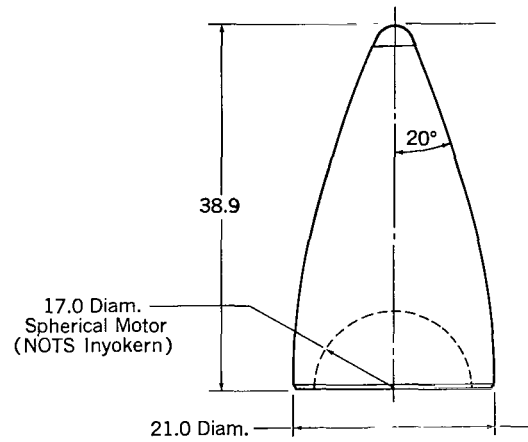
(Dimensions in inches)
(Nominal available payload volume ≈ 2.8 cu ft, estimated)
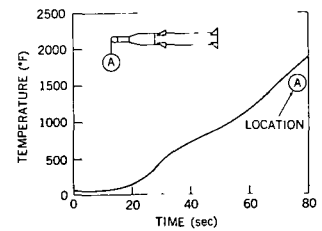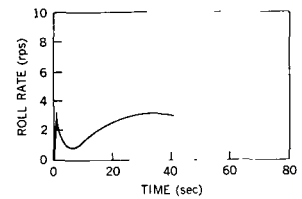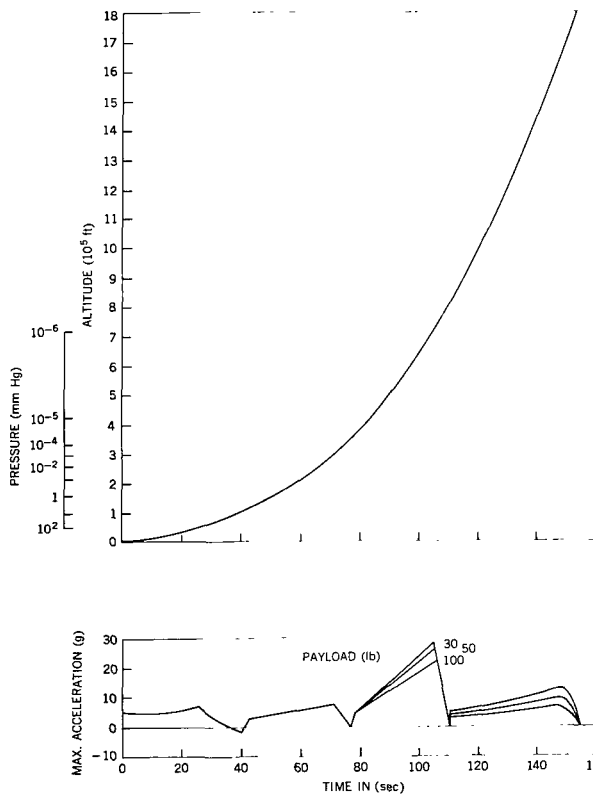
Figure 8—Launch profile for Journeyman B sounding rocket.

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LAUNCH ENVIRONMENT PROFILES FOR SPACECRAFT

Launch environment profiles for the spacecraft presently programmed for development by GSFC are dependent to a large degree on the characteristics of the launch vehicles, with smaller variations over the range of weights and trajectories of the particular spacecraft. This overall launch profile review is based, therefore, on available data relating to the following launch vehicles:

Scout   Atlas–Agena B

Delta   Centaur

Thor–Agena B

The general configurations of these launch vehicles are well-known and not repeated here. Among the specific characteristics affecting launch profiles, the following should be noted:

1. All launch vehicles are liquid propellant except Scout (four-stage, all solid propellant) and the third stage of Delta.

2. Delta and Thor-Agena B have essentially the same first stage.

3. Thor-Agena B and Atlas-Agena B have essentially the same second stage.

4. Atlas-Agena B and Centaur have essentially the same first stage.

5. Scout and Delta have essentially the same final stage.

All the launch vehicles above may utilize variable burning schedules for the upper stages, depending on the particular orbit or trajectory desired. This will affect the time history of acceleration and vibration, and the relation of pressure to acceleration and vibration (and, to a lesser extent, the relation of temperature to vibration and acceleration). It will not affect the relation of vibration to acceleration. Almost all the acoustic and aerodynamic vibration and heating inputs occur during the first stage burning and are nearly the same for all launch payloads, varying only with shroud characteristics.

Representative launch profiles for Scout, Delta, Thor-Agena B, Atlas-Agena B, and Centaur vehicles are given in Figures 9 through 13.

Figures 9 through 13 present maximum longitudinal acceleration in g's, altitude in feet, and dynamic pressure in pounds per square foot. The notations indicate staging, Mach 1, ejection of aerodynamic shroud, and spin-up, as well as levels and sources of vibration, acoustic, and heating inputs. The data sheets accompanying each plot give further information on the profiles, including magnitudes of vibration and acoustic inputs if available. The anticipated launch pad environment prior to liftoff is also given if known.

The data sheets also include a listing of typical NASA payloads launched or programmed for each launch vehicle. Manned spacecraft are not included, since these are not under the cognizance of GSFC.

The following notes apply to Figures 9 through 13:

1. Representative profiles were chosen primarily on the basis of data availability. In general, the continuous function data (acceleration, altitude, dynamic pressure) are from measured or computer trajectory print-outs for the selected spacecraft — launch-vehicle combinations. The other environmental data (vibration, acoustics, heating, and spin) are from GSFC internal reports and correspondence, and from interviews with project personnel.

2. Continuous function data are plotted against time from liftoff, in seconds. Diagonal rulings indicate a time break. Event timing is given in the horizontal bar chart of operational phases just above the plot. In addition to the plotted functions of acceleration (longitudinal), altitude, and dynamic pressure, the ambient pressure can be obtained from the altitude scale by using the following conversion table:

Pressure (mm Hg)	Altitude	
	(ft)	(10^5 ft)
10^2	49,000	0.49
10^1	98,000	0.98
10^0	147,500	1.47
10^{-1}	213,000	2.13
10^{-2}	255,000	2.55
10^{-3}	295,000	2.95
10^{-4}	337,000	3.37
10^{-5}	425,000	4.25
10^{-6}	720,000	7.20
10^{-7}	1,145,000	11.45
10^{-8}	1,735,000	17.35

3. Other environmental data are given only in qualitative form, to show how they fit into the time profile of the launch. Height of the bars for vibration and acoustic levels is indicative of order of magnitude and is consistent throughout the five profiles. Further information on these parameters (including quantitative values where available) is given on the data sheets accompanying each figure.

4. Variations of payloads and trajectory requirements from those plotted in the figures will affect the early portion of the profile very little. Variations in payload weight will affect *final* stage burnout acceleration and altitude. Variations in trajectory will affect altitude and magnitude of heating. Variation in vehicle configuration (primarily shroud changes) will affect heating and acoustics. In particular, payload changes within a given vehicle configuration will have little effect on all profile data of the vehicle's first stage (1st and 2nd stages for Scout). Consequently most vibration, acoustic, and heating inputs — which occur early in the launch phase — are similar for all payloads. For this reason it was considered acceptable to extrapolate vibration, acoustic, and heating data for payloads other than those used for the continuous function data.

5. Vibration data are generally referenced to the payload support structure. In particular, the vibration data for Delta, Thor-Agena, and Atlas-Agena are based on this reference. Vibration data

for Scout are from measurements within the lower payload section, but this is at the same location relative to the scientific payload.

     6. Acoustic data are referenced to the payload location of the launch vehicle. Data labeled "external" are referenced to the outer surface of the shroud. Data labeled "internal" are referenced to the inner surface of the shroud.

     7. Heating data are given for the external and internal surfaces of the nose cone (shroud) at the junction of the conical and cylindrical surfaces (reference point 2 feet aft of nose, for Scout). The notes accompanying the Atlas-Agena profile indicate the wide variation in external shroud temperature at different locations.

Scout (Representative Profile)

Scout . . . .   Four-stage, solid propellant

Acceleration . . . .   Longitudinal: max. = 14.5 g, 4th stage
                                                   13.8 g, 3rd stage (estimated)

                                               Lateral: none recorded, but see "Vibration"

Altitude . . . .   At end of boosted flight: 1,670,000 ft

Dynamic pressure . . . .   Maximum $\approx$ 1800 lb/sq ft at T = 35 sec

Vibration . . . .   Dominated by characteristic burning resonances of 4th stage motor (X-248). Tangential mode of resonance has frequency range of 2350 to 3700 cps and levels to 50 g-rms. Longitudinal mode has fundamental frequency at 580 cps and second harmonic at 1160 cps, with level up to 17.8 g-rms at 580 cps and 8.9 g-rms at 1160 cps — on the longitudinal axis.

     Approx. vibration limits from St-9 data (total duration, up to 40 sec):

         Longitudinal: 580 cps, to 17.8 g-rms
                       1160 cps, to 8.9 g-rms
                       2350-3700 cps, to 29.4 g-rms
       Lateral: 580 cps, to 5.9 g-rms
                 1160 cps, to 2.5 g-rms

     (Further vibration data on X-248 motor and Scout rocket are available in NASA-GSFC Test and Evaluation memos 621-36 (St-9) and 621-4 (St-7); see Bibliography.)

Acoustics . . . .   Powerplant noise at launch T = 0 approx. flat at 140 db/octave band from 40 to 2000 cps, reduced by 15 to 20 db after 2 sec.

     Aerodynamic noise peaks at maximum dynamic pressure q_{max} (T = 35 sec) at approx. 140 db/octave band from 800 to 8000 cps (these are external levels).
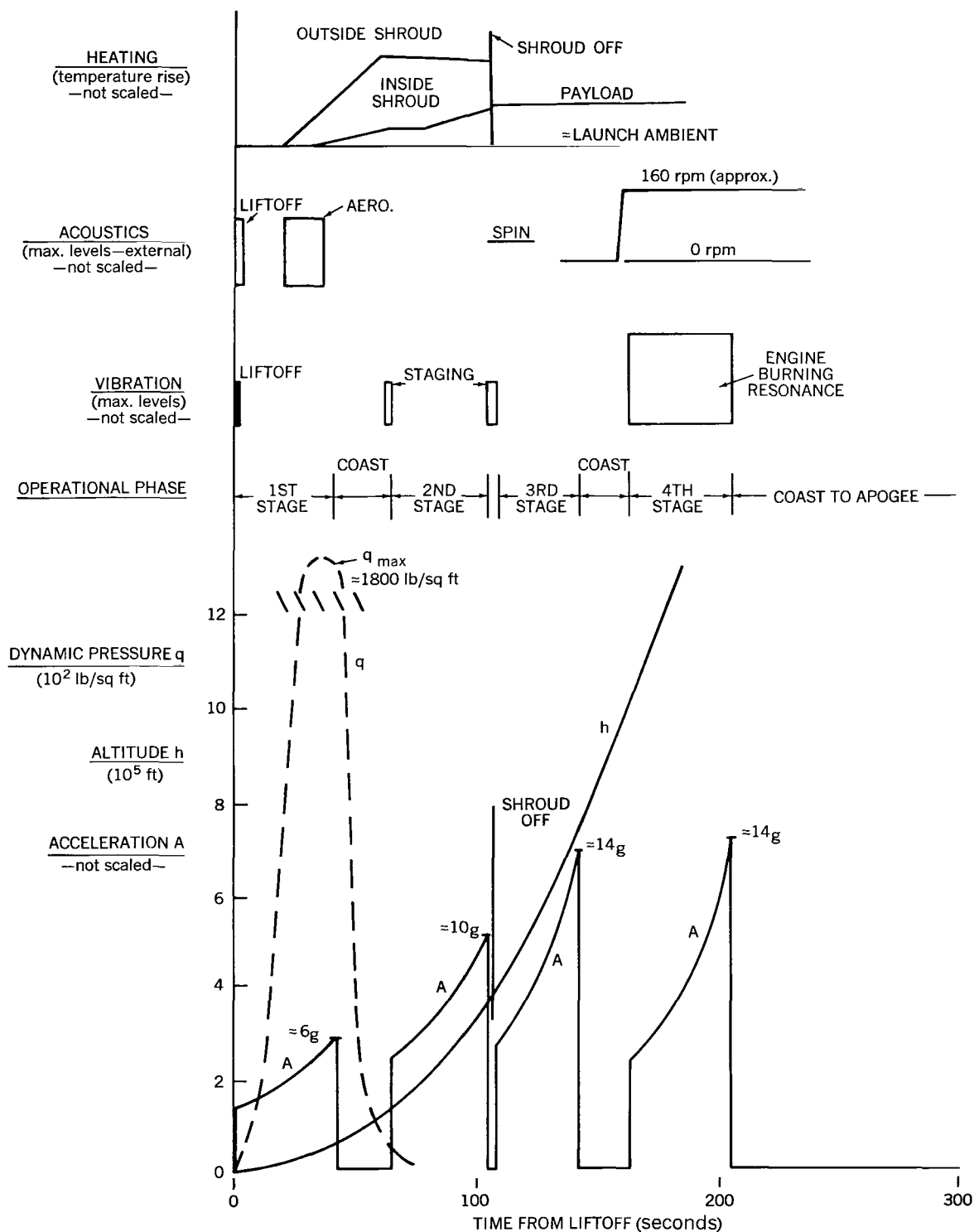
Figure 9—Representative launch profile for Scout vehicle (St-9/p 21a profile; payload, 150 lb).

Heating . . . .   Outside heat shield at 2 ft behind nose: Temperature rises from ambient to about 600°F at T = 50 sec (probe trajectory) and drops off slowly to 500°F at T = 100 sec.

Inside heat shield at same point: Temperature rises from ambient to about 100°F at 100 sec.

Heat shield ejected before 3rd stage ignition (T = 100 sec): Payload temperature on St-7 gave erratic readings, but steady-state maximum for T = 200 sec to T = 600 sec was 120°F.

Spin . . . .   Approx. 160 rpm, initiated just before 4th stage ignition and continuing after final burnout.

Pad environment
prior to T = 0 . . . .   Air conditioning required for 4th stage motor.

Typical payloads (in lb) for Scout (NASA only); capability — 150 lb to 300-mile orbit and 250 lb for advanced versions:

Ariel II (S-52; UK-2)	165
Polar Ionosphere Beacon (S-66)	70
Fixed Frequency Topside Sounder (S-48)	110
Micrometeoroid Satellite (S-55)	135

Delta (Representative Profile)

Delta. . . . .   Three-stage; 1st and 2nd, liquid propellant; and 3rd, solid propellant

1st stage is Thor engine, essentially same as in Thor-Agena B vehicle

3rd stage is X-248, same as 4th stage of Scout

Acceleration . . . .   Longitudinal: max. $\approx$ 18.0 g, 3rd stage
$\approx$ 12.5 g, 1st stage
Lateral: none recorded, but see "Vibration"

Altitude . . . .   At end of powered flight, T $\approx$ 700 sec: 970,000 ft

Dynamic pressure . . . .   Maximum $\approx$ 930 lb/sq ft at T = 66 sec

Vibration . . . .   As with Scout, dominated by X-248 burning resonances at 580 cps, and 2350 to 3700 cps in first half of burning. (See vibration data for Scout; also NASA-GSFC Test and Evaluation memo 621-37 on Delta-9 (S51/UK-1) test — see Bibliography)

Figure 10—Representative launch profile for Delta vehicle (S-3 profile; payload, 85 lb).
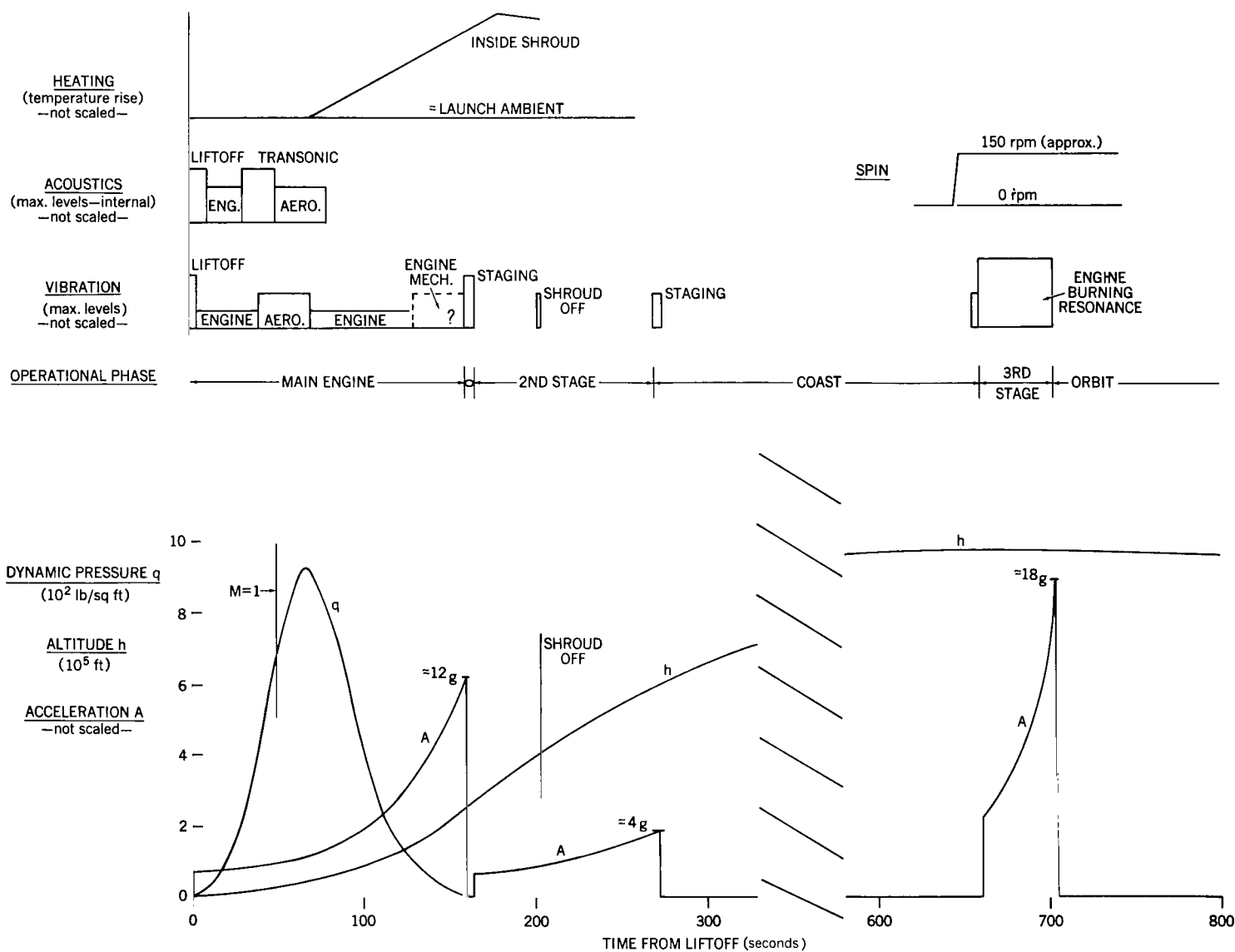
Vibration (Cont.) . . . .   Other vibrations: aerodynamic inputs near Mach 1 and q_{max} during first stage, and a possible longitudinal mode near end of 1st stage burning, T = 130 to 160 sec, up to ±2.8 g-peak. Other tests (AVT-1) on NASA vehicles using same 1st stage give up to 7 g-rms longitudinal near Mach 1 and 3 g-rms lateral at the same time.

Approx. maximum limits, based on these limited data:

Stage	Frequency (cps)	Maximum Acceleration (g-rms)
Longitudinal		
1st Stage (Mach 1, q_{max})	400-2100	7
3rd Stage (X-248 resonance)	580 1160 2350-3700	18 9 30
Lateral		
1st Stage (Mach 1, q_{max})	400-2100	3
3rd Stage	580 1160 2350-3700	6 2.5 52

(See data sheets for Scout and Thor-Agena B)

Acoustics . . . .   Maximum noise levels at liftoff T = 0 to T = 10 sec, also
N. B.
Changes with varying
shroud configuration
at possible shroud coincidence-resonance at Mach 0.5. Other high noise levels near Mach 1 and possibly at q_{max}.

Estimated overall noise levels at liftoff up to 145 db external, possibly up to 8 db higher at Mach 0.5; noise decays rapidly after q_{max} (T = 66 sec).

Noise spectra peak at 150 to max 300 cps external and about one octave higher, internal.

Heating . . . .   Inside shroud (only available data): Temperature at junction of nose cone and cylindrical section rises from ambient to 450°-500°F at about T = 190 sec, and slowly decreases (data for Ariel I shroud and trajectory). This is for fiber glass shroud (0.10 in.) without insulation in cylindrical section.

Spin . . . .   Approx. 150 rpm, initiated before 3rd stage ignition and continuing after final burnout.

Pad environment
 prior to T = 0 . . . .   Air conditioning required for 3rd stage motor.

Typical payloads (lb) for Delta (NASA only); capability – 500 lb to 300-mile orbit:

Tiros	285
Orbiting Solar Observatory (S-17)	440
Relay (A-15)	170
Syncom	70
Telstar	170
Interplanetary Monitoring Probe (S-74)	125
Atmospheric Structure Satellite (S-6)	375
Ariel I (S-51; UK-1)	150
Energetic Particles Satellite (S-3a; S-3b)	100
Echo	200

Thor-Agena B (Representative Profile)

Thor-Agena B . . . .   Two-stage, liquid propellant
 1st stage, essentially same as 1st stage of Delta vehicle

 2nd stage, essentially same as 2nd stage of Atlas-
Agena B vehicle

Acceleration . . . .   Longitudinal: max. $\approx$ 7.5 g, 1st stage
 $\approx$ 6.0 g, 2nd stage

 Lateral: none recorded

Altitude . . . .   At end of boosted flight, T = 3160 sec: $\approx$ 851,000 ft

Dynamic pressure . . . .   Maximum $\approx$ 900 lb/sq ft at T = 66 sec

Vibration . . . .   Highest vibration input (low and high frequency) at lift-
off, other low frequency vibrations at staging; high frequency
vibration peak at Mach 1 to q_{max} . Possible low frequency
longitudinal mode, resulting from engine mechanical system,
existing for about 20 sec prior to 1st stage (main engine)
cutoff. This mode may give up to $\pm$2.8 g-peak at 16 to 22 cps.

 Approx. limits from recent test data are given on
page 22.
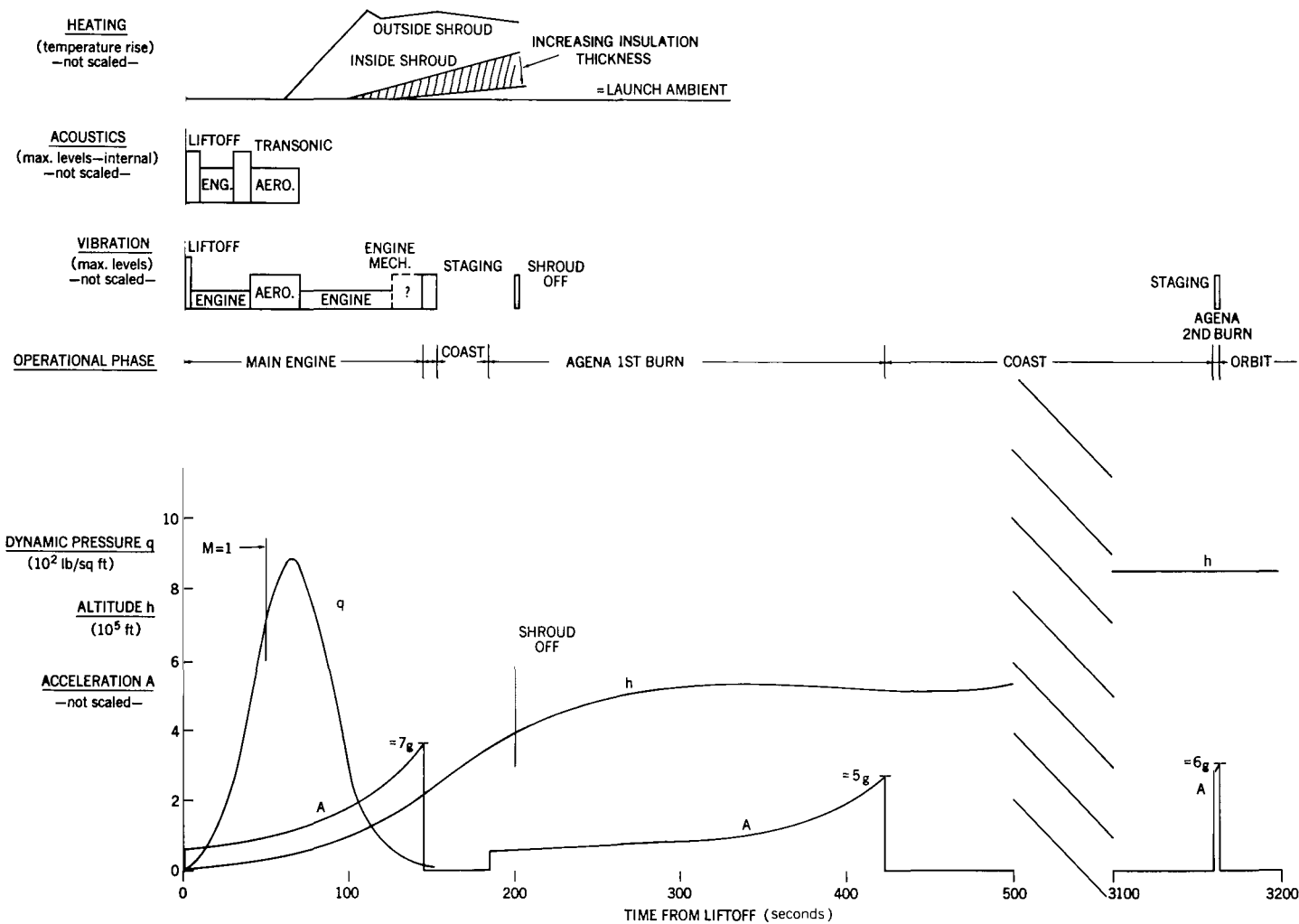
Figure 11—Representative launch profile for Thor-Agena B vehicle (POGO profile; payload, 1000 lb).

Vibration (Cont.) . . . .

Frequency, Sinusoidal (cps)	Peak (g)
Longitudinal	
8-16	±1.5
16-22	±2.8
22-100	±1.5
100-250	±2.2
250-400	±3.3
400-2000	±5.0
Lateral	
5-100	±1.0
100-400	±1.5
400-2000	±5.0

Acoustics . . . . (Approx. same as given for Delta, but more reliable here.)

Maximum noise levels at liftoff, T = 0 to T = 10 sec, also at possible shroud coincidence-resonance at Mach 0.5. Other high noise levels near Mach 1 and possibly at q_{max} .

Estimated overall noise levels at liftoff up to 145 db external and 130 db internal, possibly up to 8 db higher at Mach 0.5; noise decays rapidly after q_{max} (T = 66 sec).

Noise spectra peak at 150 to 300 cps external and about one octave higher, internal.

Heating . . . . External temperature at junction of nose cone and cylindrical section rises from ambient up to T = 60 sec, to about 300°F at T = 110 sec, then decreases slowly. Temperature inside shroud at same point rises slowly from ambient, to 100° to 230°F, depending on the thickness of the insulation. The shroud is ejected at T = 200 sec, carrying most of the heat input with it.

Spin . . . . Not used during powered flight.

Pad environment
  prior to T = 0 . . . . Probably air-conditioned on pad, but may be unprotected at times.

Typical Thor-Agena B payloads (NASA only); capability — 1600 lb to 300-mile orbit:

POGO (S-50)	1000 lb, 4 ft diam. by 10 ft long	Alouette (S-27; Canadian)	300 lb
Echo-2	650 lb	POGO in shroud	1400 lb, 5.5 ft diam. by 18 ft long
Nimbus	650 lb, 5 ft diam. by 10 ft long	Nimbus in shroud	1100 lb, 5.5 ft diam. by 16 ft long

Atlas-Agena B (Representative Profile)

Atlas-Agena B . . . . Two-stage, liquid propellant

        1st stage is essentially same as in Centaur vehicle.
2nd stage is essentially same as in Thor-Agena B vehicle.

Acceleration . . . . Longitudinal: max. ≈ 6.5 g, 1st stage
                     ≈ 6.0 g, 2nd stage

        Lateral: none recorded

Altitude . . . . At end of boosted flight, T = 3475 sec: $\approx$ 930,000 ft

Dynamic pressure . . . . Maximum $\approx$ 870 lb/sq ft at T = 70 sec.

Vibration . . . . Highest vibration input at liftoff (high and low frequency excitation), low frequency vibrations at staging; high frequency vibrations in transonic-q_{max} regime.

        Approx. spectrum:

           Longitudinal: 10-250 cps, ±1.5 g (sinusoidal)
                              250-400 cps, ±2.5 g (sinusoidal)
                              400-3000 cps, ±5.0 g (sinusoidal)
           Lateral: 2.5-250 cps, ±1.0 g (sinusoidal)
                                250-400 cps, ±2.0 g (sinusoidal)
                                400-3000 cps, ±5.0 g (sinusoidal)

Acoustics . . . . Maximum noise levels at liftoff; and, in transonic range, other high levels may exist at q_{max}.

        External noise level near nose cone—cylindrical-section junction, about 128 db overall at liftoff and again at about Mach 0.8 (T = 45 sec), peaking between 600 and 1200 cps.

Heating . . . . External temperature near junction of nose cone and cylindrical section rises from ambient (up to T = 60 sec) up to about 350°F at T = 105 sec, then decreases very slowly. Temperature inside shroud at same point rises slowly from ambient to 100°-250°F, depending on the thickness of insulation. The shroud is ejected near first Agena ignition, carrying most of the heat input away. *External temperatures are very much a function of the location of the measurement point.* For example, the external temperature at the tip of the nose cone rises to near 1600°F at about T = 160 sec, then decreases to 800°F by the time of shroud ejection.

Spin . . . . Not used during powered flight.

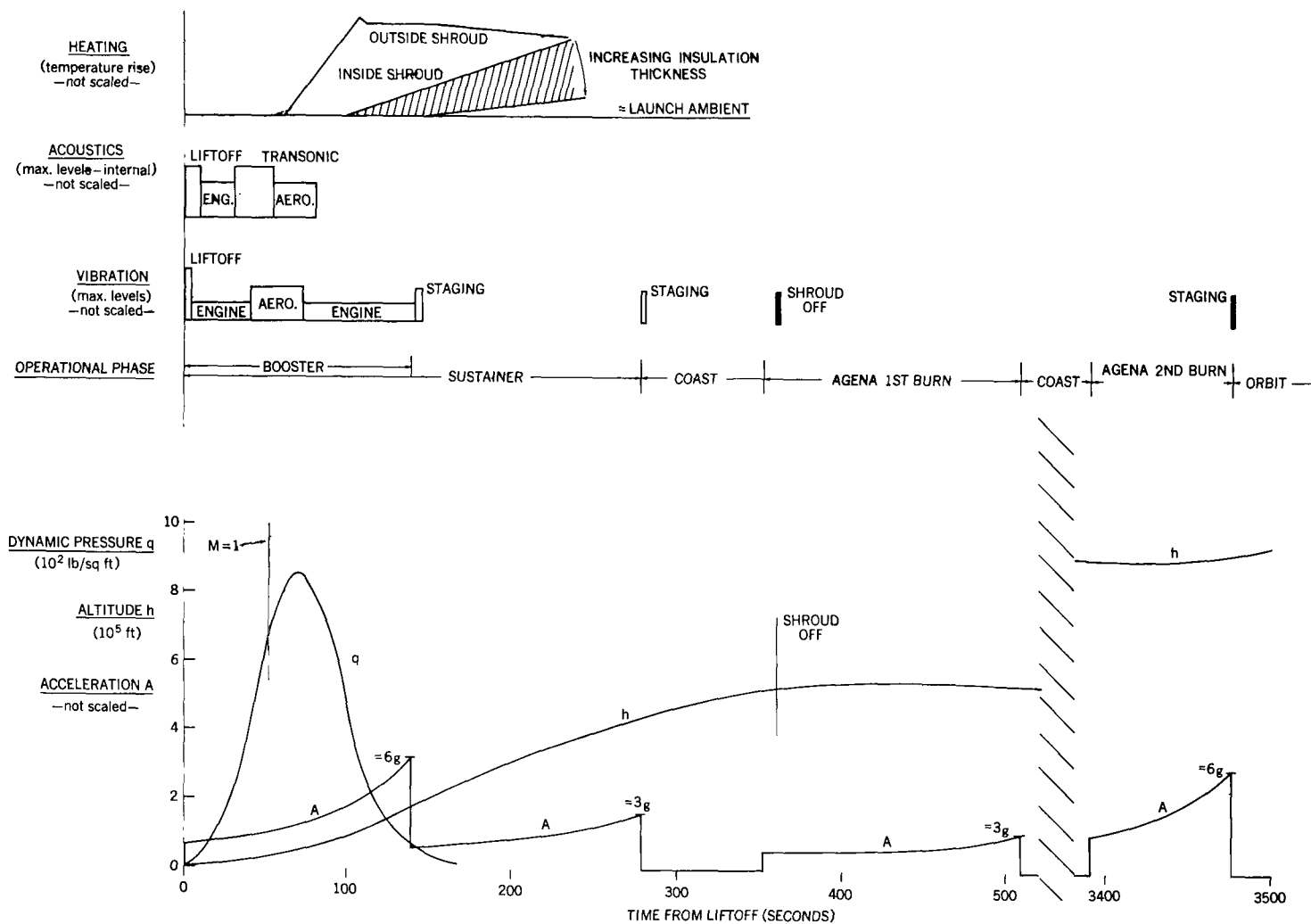Figure 12—Representative launch profile for Atlas–Agena B vehicle (EGO profile; payload, 1000 lb).

Pad environment
    prior to T = 0 . . . . Probably air-conditioned on pad, but may be unprotected
                                                     at times.

Typical Atlas-Agena B payloads (NASA only); capability — 5000 lb to 300-mile orbit:

EGO (S-49)	1000 lb, 4 ft diam. by 10 ft long
OAO (S-18)	3600 lb, 8 ft diam. by 12 ft long
Ranger	700 lb (GSFC experiment)
Mariner A	500 lb (GSFC experiment)
Syncom (Advanced)	500 lb
OAO in shroud	4700 lb, 10 ft diam. by 26 ft long
EGO in shroud	1400 lb, 5.5 ft diam. by 18 ft long

Centaur (Representative Profile)

Centaur . . . . Two-stage, liquid propellant
                                                     1st stage, essentially same as 1st stage of Atlas-
                                                Agena B
                                                     2nd stage — high energy engine, same as upper stage
                                                engines of Saturn C-1 vehicle under development

Acceleration . . . . Longitudinal: max ≈ 8.0 g, 2nd stage
                                                                       ≈ 6.0 g, 1st stage
                                                     Lateral: none recorded

Altitude . . . . Final boost into 24-hr orbit, 19,329 nautical miles at
                                                $T \approx 22{,}900$ sec (6 hr, 22 min)

Dynamic pressure . . . . Maximum ≈ 800 lb/sq ft at T = 84 sec

Vibration . . . . Data not available
   (see Atlas-Agena B)   1st stage vibration extrapolated from Atlas-Agena B
                                                data sheet and probably quite similar.

                                                     Vibration characteristics of 2nd stage engine are
                                                unknown.

Acoustics . . . . Data not available; external noise levels probably follow
   (see Atlas-Agena B)   those for Atlas-Agena B. Noise attenuation of Centaur shroud
                                                is unknown at time of writing.

Heating . . . . Data not available.
                                                     It is interesting to note that both heating and cooling may
                                                be a problem. For example, the S-64 spacecraft for 24-hr
                                                orbit launch on Centaur (piggyback load) is limited to a maxi-
                                                mum temperature exposure of 250°F and a minimum tem-
                                                perature of -140°F (solar paddles). Because of the long
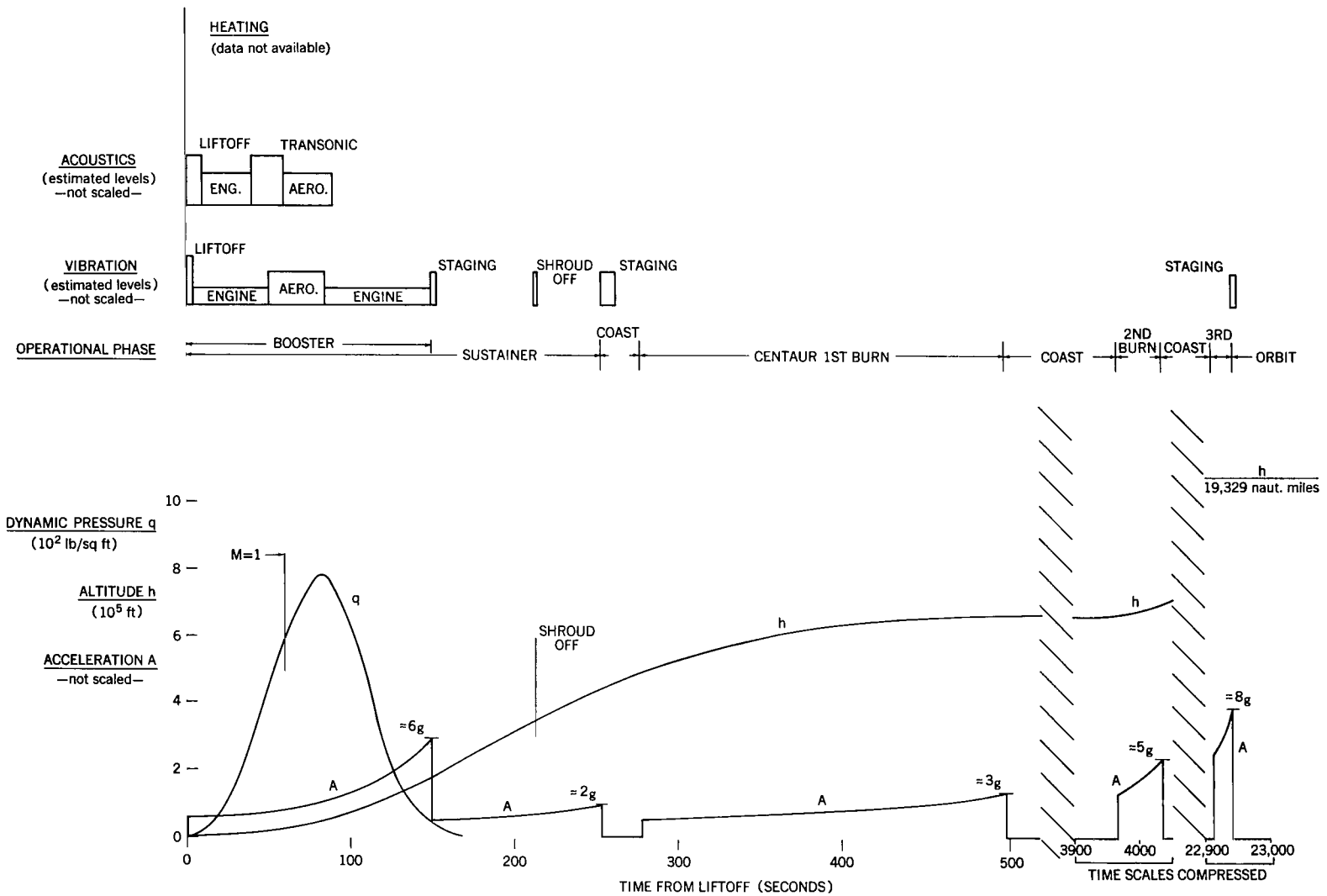
Figure 13—Representative launch profile for Centaur vehicle (24-hr orbit profile; payload, 850 lb).

Heating (Cont.) . . . .   coast time in the launch vehicle shadow (spacecraft end
away from sun), it must be protected against cooling as well
as heating. Thus, the S-64 has two shrouds; one is jettisoned
during sustainer burning, the other at spacecraft separation
from 2nd stage.

Spin . . . .   Not used during powered flight.

Pad environment
   prior to T = 0 . . . .   Unknown

Typical Centaur payloads (NASA only); capability — 8500 lb to 300-mile orbit:

Radiation Measurements Payload (S-64)	112 lb; piggyback load total 450 lb, 5 ft diam. by 10 ft long
Surveyor	2000 lb (GSFC experiment)
Mariner B	1300 lb (GSFC experiment)
S-64 ir shroud	≈ 1000 lb total, 10 ft by 18 ft long

DISCUSSION OF LAUNCH PROFILE PARAMETERS

The launch environment profiles given in Figures 1 through 13, with accompanying data, form
the basis for an envelope of launch phase environmental parameters. This envelope is, in effect, the
overall combination of flight level environmental inputs imposed on the payloads of sounding rockets
and unmanned spacecraft launch vehicles.

Changes in the levels of environmental parameters due to new developments in launch vehicle
technology also should be considered. A review of this problem by the authors shows that the pri-
mary effect of anticipated developments in the period to 1970 will be the extension of acceleration
levels for large spacecraft (those over 1000 lb). This is included in the discussion of acceleration
levels below. Notations on possible changes in levels of other inputs are also included.

The summarized levels of environmental parameters given here are classified primarily by
spacecraft weight. Combinations of parameters that exist simultaneously during the launch phase
are indicated. These are the most severe combinations for likely NASA sounding rocket and space-
craft vehicle configurations and missions, although other combinations are theoretically possible.

The following parameters have been considered in the discussion:
1. Acceleration — longitudinal
2. Acceleration — lateral
3. Pressure (altitude)
4. Vibration
5. Acoustics
6. Heating
7. Spin

Acceleration — Longitudinal

1. *Accelerations range from 60 g for payloads of 50 lb to 15 g for payloads of 300 lb for sounding rockets, and from 36 g for payloads of 50 lb to 6.5 g for payloads of 2000 to 4000 lb for spacecraft.*

The envelope of maximum acceleration imposed on unmanned spacecraft during the launch phase is given in Figure 14. This figure gives maximum longitudinal acceleration as a function of payload weight. The lower solid curve gives accelerations imposed by present spacecraft launch vehicles including Scout, Delta, Thor-Agena, Atlas-Agena, and Centaur. Programmed improvements in individual stage propulsion are included. The near-vertical solid curve gives accelerations imposed on sounding rocket payloads. The estimated accelerations for future NASA launch vehicles are given by the upper solid curve. These are based on a brief review of development programs for large boost vehicles including Saturn, Nova, Titan II, and Titan III and of anticipated developments in solid and liquid rocket engines.
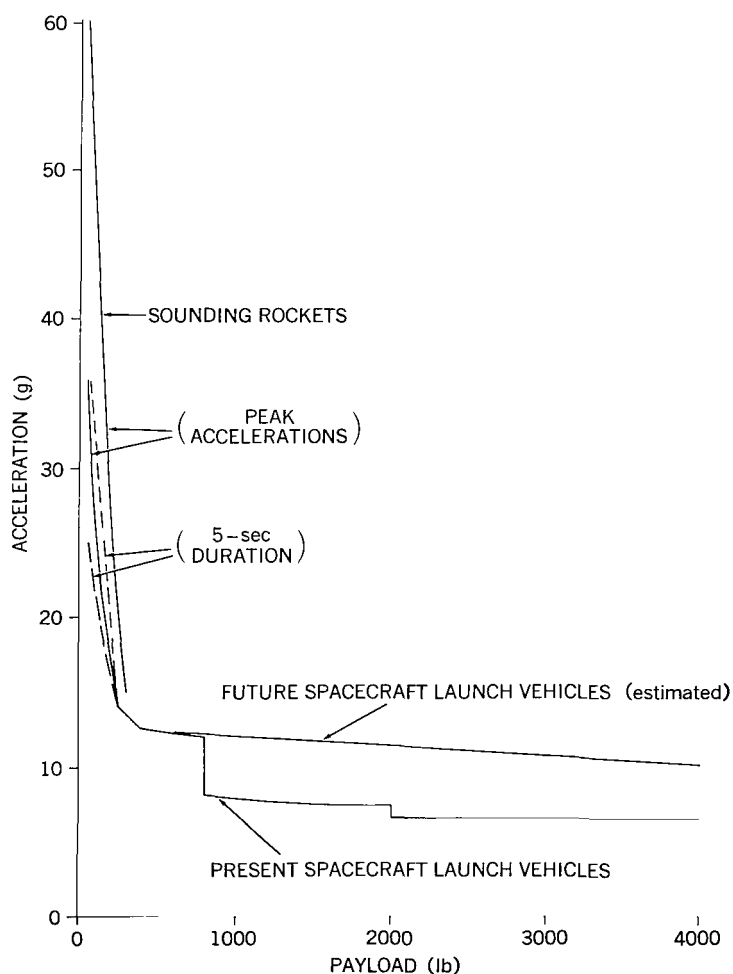
Figure 14—Envelope of spacecraft and sounding rocket maximum acceleration during launch phase.

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The high acceleration peaks for the payloads less than 300 lb occur only momentarily at burnout of the boost rocket stages. The dotted curves in Figure 14, showing accelerations of 5-sec duration, give an indication of the sharpness of these peaks and of the problem of simulating acceleration and combined environmental inputs for this range of payloads.

Accelerations for spacecraft launch vehicles range from 36 g for payloads of 50 lb to 12 g for payloads of 400 to 800 lb, 8 g for payloads of 800 to 2000 lb, and 6.5 g for payloads of 2000 to 4000 lb.

Estimated accelerations for future launch vehicles range from about 12 g for payloads of 1000 lb to 10 g for payloads of 4000 lb.

2. *The anticipated levels of acceleration imposed by future launch vehicles will not be significantly higher than those at present except that the payload range of 1000 to 4000 lb may be subjected to accelerations on the order of 10 to 12 g.*

Estimation of maximum launch acceleration levels that might be imposed on unmanned spacecraft by future launch vehicles was accomplished by a brief review of published material on vehicle and motor development program.

The trend in large solid rockets is toward application of built-up boosters in the liftoff stage, where size and weight are important. Liquid rockets such as the Agena series and the newer hydrogen/oxygen engines (e.g., Centaur) will continue to provide the upper stage propulsion for vehicles such as Titan III and Saturn C-1.

In general, the emphasis is toward large payloads and low accelerations suitable for the manned space flight missions. It is true that high accelerations can be imposed on small payloads attached to large boosters having high thrust/weight ratios. However, the normal vehicle stage weights and thrust/weight ratios limit these accelerations for practical vehicle/payload combinations.

Acceleration — Lateral

Data on lateral accelerations during the launch phase have been conspicuously absent during this study.

Flight level lateral accelerations are usually much lower than those anticipated during transportation and handling of the payload prior to launch. For flight programmed pitch and yaw motions, the lateral acceleration loads are normally less than 0.2 g although, for one of the vehicles considered, these loads reached 0.4 g. These are all small compared with the maximum lateral accelerations due to handling, which are 1.5 to 2.0 g.

There appears to be no requirement for testing under combined longitudinal and lateral acceleration loadings. Payload test specifications may include provisions against conduct of such tests, which are considered to be unrealistic environments.

Pressure (Altitude)

The achievement of high altitude (low pressure) during the launch phase is associated with all acceleration levels and payload weights.

The following rates of pressure change apply:

      Large launch vehicles: Delta and up, to 10^{-2} mm Hg in 150 to 180 sec

      Small launch vehicles: Scout and sounding rockets, to 10^{-2} mm Hg in 60 to 100 sec

Maximum altitudes (pressure levels) reached during the launch phase are:

Large satellite vehicles:	10^{-7} mm Hg (except 24-hr orbit, 10^{-9} mm)
Probes:	10^{-8} mm Hg
Sounding rockets:	1 mm to 10^{-8} mm Hg

Most orbiting spacecraft exceed altitudes corresponding to 10^{-5} mm Hg.

Future levels are anticipated to be the same as present levels.

Vibration

Vibration inputs up to the maximum levels measured can be combined with the highest acceleration loads.

Vibration inputs from rocket combustion, mechanical, and aerodynamic sources can occur throughout all of the flight launch phase. Lateral and longitudinal vibrations are very often of the same order of magnitude, occurring simultaneously.

It is much more difficult to define an envelope of vibration levels. The following is a rough summary of vibration flight levels.

1. Payloads of approx. 1000 lb

      Longitudinal: 10-250 cps, ±2.5 g (peak sinusoidal)
                          250-400 cps, ±3.3 g (peak sinusoidal)
                          400-2000 cps, ±5.0 g (peak sinusoidal)

      Lateral: 10-250 cps, ±1.5 g (peak sinusoidal)
                          250-400 cps, ±2.0 g (peak sinusoidal)
                          400-2000 cps, ±5.0 g (peak sinusoidal)

Insufficient data exist for determining random acceleration levels.

2. Payloads up to 500 to 600 lb

In addition to the sinusoidal accelerations given under no. 1 above, it is necessary to consider the large accelerations that may arise from rocket motor resonance burning — specifically the X-248 motor, which is the final stage for Delta, Scout, Javelin, and Journeyman vehicles. This motor has burning resonances at approximately 580 and 1160 cps, and also a range between 2350 and

3700 cps. While these burning resonances are of only a few seconds duration, magnitudes of vibration are very high; for example, the following were measured on a Scout test (150-lb payload):

Longitudinal: 580 cps, to 18 g-rms
1160 cps, to 9 g-rms
2350-3700 cps, to 29 g-rms

Lateral: 580 cps, to 6 g-rms
1160 cps, to 3 g-rms
2350-3700 cps, to 52 g-rms

The Bibliography given in this report contains a number of references related to these engine burning resonances, on Scout and Delta launch vehicles and Javelin sounding rockets.

Vibration levels imposed by future launch vehicles are expected to be of the same order of magnitude as the present ones. It is possible that rocket motors having burning resonances similar to that of the X-248 (perhaps at different frequency ranges) may be used.

Acoustics

Acoustic excitations are at their highest level during the early phases of launch, with primary peaks at liftoff and in the Mach 1 to q_{max} regime.

For all vehicles except sounding rockets, the maximum acoustic inputs occur at acceleration levels less than about 6 g and at altitudes corresponding to pressure levels from atmospheric to about 100 mm Hg. For sounding rockets (payloads up to 300 lb) large acoustic inputs may be associated with accelerations up to 30 g.

Maximum sound pressure levels of overall acoustic inputs range up to about 155 db (external). Internal sound pressure levels are not very well defined, but mostly are 10 db or more below the maximum external sound pressure levels.

Acoustic inputs for future vehicles may be slightly higher than those for present vehicles. An accurate assessment is not possible at this time.

Heating

Aerodynamic heating during the launch phase is of short duration but can be quite intense on the exterior of the shroud. Most of the heat absorbed by the shroud during launch is carried away when the shroud is jettisoned.

The rates of temperature rise for the exterior of the shroud are generally within the following envelopes:

1. Sounding rockets: nose cone stagnation temperature from ambient to 1600°F in 60 sec; shroud temperature at forward cylindrical section to 800°F in 60 sec.

2. Spacecraft launch vehicles: nose cone stagnation temperature from ambient to 1600°F in 100 sec; shroud temperature at forward cylindrical section to 600°F in 100 sec.

Peak internal surface temperatures of the shroud are much lower than peak external temperatures and are reached more slowly. For spacecraft launch vehicles, the maximum internal temperature in the forward cylindrical section is about 300°F, reached in 200 sec. After shroud ejection the payload is subjected to direct solar radiation and free molecular heating. Temperature change on the payload after shroud ejection is dependent on payload material, surface finish and color, and vehicle trajectory.

Heating inputs for future launch vehicles are not expected to exceed present levels.

Spin

Many payloads are subjected to spin during missions, but only a few are spun during the launch phase. Spin during the launch phase is often associated with high acceleration and vibration levels.

Most sounding rockets are spin-stabilized, with spin rates up to 300 to 600 rpm for payloads up to 300 lb. The spin rates may be associated with acceleration levels up to 30 g as well as high vibration, acoustic, and heating inputs.

Payloads on Scout and Delta launch vehicles are also subjected to spin, during last stage burning (X-248 motor). Spin rates are about 150 to 180 rpm for payloads up to 500 to 600 lb. These spin rates may be associated with maximum acceleration levels for the payload weight and with high vibration levels. Acoustic and heating inputs are not present.

There is no information on possible spin requirements that future launch vehicles may impose on larger payloads.

APPLICATION TO LAUNCH PHASE SIMULATOR

The survey of launch environment profiles summarized in this report can be used to assist in the development of design and operational requirements for the Launch Phase Simulator. The magnitude of each environmental parameter and the extent to which the parameters are combined can be determined from the profiles. Simulation of all parameters in "real time" corresponding to the launch phase of flight missions may not be possible in the Launch Phase Simulator. However, these data provide an overall envelope of the design and operation criteria for this new environmental test facility.

BIBLIOGRAPHY

The launch profile data in this report have been assembled from a wide variety of sources. While it would be very difficult to list references for each item of the profiles, the following have been primary data sources.

Sounding Rockets

Most of the profile data for sounding rockets is from the Sounding Rocket Handbook series prepared by Vought Astronautics, a Division of Chance Vought Corporation, for NASA under contract NAS 1-1013. Altogether, eighteen vehicles are covered in the Handbook series; eight of these were chosen for inclusion in this study. The data are fairly complete, except for vibration inputs.

Additional data on vibration inputs for sounding rockets are given in the following reports:

Oleson, M. W., "Report on Acceleration and Vibration Data from Javelin (8.02) Vehicle," Naval Research Laboratory Memo Report 1074, July 1960.

Nagy, J. A., "Vibration Experiments of Aerobee, NASA 4.20 and NASA 4.68," NASA-GSFC Test and Evaluation (T&E) Division Memo Report 621-35, May 18, 1962.

Elsen, W. G., "Vibration Experiments of IRIS, NASA 5.04," NASA-GSFC T&E Memo Report 621-41, May 28, 1962.

Spacecraft

Launch profile data for spacecraft other than sounding rockets are from two primary sources: Trajectory data for launch vehicles (acceleration, altitude, dynamic pressure) are adapted from computer trajectory print-outs contained in reports by the launch vehicle contractors, except that Scout data are computed from NASA test results. Data on vibration, acoustics, heating, and spin are mostly from NASA published and internal reports and from technical reports of vehicle contractors.

Among the sources consulted for vibration and acoustic data are:

NASA-Langley Scout Vehicle Manual, July 1960.

Posner, J., "Considerations Affecting Satellite and Space Probe Research with Emphasis on the Scout as a Launch Vehicle," NASA Technical Report R-97.

Mayes, W. H., Hilton, D. A., and Hardesty, C. A., "In-Flight Noise Measurements for Three Project Mercury Vehicles," NASA Technical Note D-997, January 1962.

Bangs, W. F., "Vibration Experiment of Scout ST-7/P-21," NASA-GSFC T&E Memo Report 621-4, November 27, 1961.

Tereniak, W. B., "Preliminary Analysis of Echo A-12 (AVT-1) In-Flight Vibration Data," NASA-GSFC T&E Memo Report 621-10, February 2, 1962.

Tereniak, W. B., "Scout ST-9/P21a Vibration Experiment," NASA-GSFC T&E Memo Report 621-36, May 19, 1962.

Williams, L. A., "Vibration Experiment of Delta 9 (S-51/UK-1)," NASA-GSFC T&E Memo Report 621-37, May 21, 1962.

Sources for heating inputs include:

NASA-Langley Scout Vehicle Manual, July 1960.

Boeckel, J. H., "In-Flight Temperatures of the Scout ST-7/P-21 Ionospheric Probe," NASA-GSFC T&E Memo Report 320-34-61, January 4, 1962.

Spin data are taken from vehicle specifications and vibration test reports for Scout and Delta.

Other Data Sources

Other data sources include a literature survey of scientific and technical publications, Lockheed Missiles and Space Company internal reports and reports to NASA on Agena shroud heating, Douglas Aircraft Company reports to NASA on Delta shroud heating, review of NASA program planning reports, and inputs from other Booz·Allen Applied Research, Inc. programs in astronautics. These sources were particularly useful in extrapolating launch profile parameters to future launch vehicles. Discussions were held with members of the professional staff at GSFC, including T&E Division Test Coordinators and the Spacecraft System and Project Division Vehicle Managers.

The launch profiles contained in this report represent the best application of all these sources.